

PATENT APPLICATION
OF
DAVID CALLEY
FOR
ELECTRICAL MACHINE IMPROVEMENT

Sheets of Drawings: 3

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Electrical Machine

Related Applications

This application is a Continuation In Part of co-pending US Patent Application
5 Number 10/273,238 which was filed on October 17, 2002 and which claimed priority
under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Number 60/333,248
which was filed on November 23, 2001.

Field of the Invention

Embodiments of the invention relate to an electrical machine that can function as
10 either a motor or a generator. The machine uses high frequency commutation of
magnetic flux to achieve high efficiency and high power density.

Background of the Invention

In co-pending US Patent Application Number 10/273,238, included herein by
reference, an electrical machine is described which uses a plurality of flux conductors
15 interspersed with each other around the circumference of the machine. Each of these flux
conductors has opposite magnetic polarity to the adjacent flux conductors. In this design
the number of flux conductors which could be arranged around a circumference was
limited by the necessity of leaving an air gap between adjacent laminates sufficient to
minimize flux leakage. Nevertheless, a certain amount of flux leakage is inevitable in
20 this design. It would be advantageous to provide a design which allows for closer
spacing of laminates, thus allowing for a greater number of poles and decreasing the
amount of flux leakage inherent in the geometry.

Co-pending US Patent Application Number 10/273,238 describes flux switches
which magnetically connect with the flux conductors over a small air gap between flat

terminations. There is a certain amount of reluctance to flux passage which is dictated by the width of the air gap and the surface area of the air gap. It would be advantageous to provide a flux switch geometry which would increase the surface area of the air gap thus reducing magnetic reluctance between the flux switch and the flux conductor.

5 Furthermore, the thickness of the flux switches in the Calley patent is limited by the necessity not to bridge the gap between adjacent flux conductors at the point of connection. By thus limiting the thickness of the flux switches to the thickness of the termination at the connection point a high flux density is indicated for the entire flux switch substantially similar to that at the termination point. It would be advantageous to
10 provide a way to decrease flux density in the bulk of the flux conductor.

Summary of the Invention

 The present invention discloses improvements to the electrical machine described in co-pending US Patent Application Number 10/273,238. These improvements
15 substantially increase the performance of the electrical machine described in co-pending US Patent Application Number 10/273,238 by decreasing flux loss and allowing for a greater number of poles to be used in the same diameter machine.

 The present invention alters the geometry such that the flux conductors are no longer interspersed with each other. By doing so, the amount of area for passive flux
20 leakage is greatly reduced and the number of poles is only limited by the thickness of material at the terminal ends of the flux switches and flux conductors.

 Magnetic losses are reduced using the improvements of the present invention by forming the flux conductors and flux switches with a tapered thickness near their terminal ends. Thus the body of the flux switch experiences lower flux density than the

termination thereby minimizing the volume of material experiencing high flux densities.

The tapered ends of the flux switches also allow adjacent pairs of flux conductors and switches to be placed in closer proximity to each other, thereby increasing the number of poles that are possible for a machine of a given diameter. The tapered ends of the flux

5 conductors and flux switches reduce the span required to contact two adjacent flux conductors simultaneously, thereby allowing closer placement of adjacent flux conductors.

Magnetic reluctance is reduced by providing serrated terminations to the flux switches and flux conductors. By intermeshing these serrations the surface area of the
10 connection between the two is greater and thus the magnetic reluctance of the gap is reduced.

Brief Description of the Drawings

Features and advantages according to embodiments of the invention will be apparent from the following Detailed Description taken in conjunction with the
15 accompanying drawings, in which:

FIG 1 shows an exploded view of an electrical machine according to an embodiment of the present invention.

FIG 2 shows a first cut away view according to an embodiment of the present invention.

20 FIG 3 shows a second cut away view according to an embodiment of the present invention.

FIG 4 shows a close-up view taken in circle 4 of Figure 3.

FIG 5 shows a close-up plan view of a terminating end of a flux conductor and a flux switch according to an embodiment of the present invention.

Detailed Description of the Drawings

The present invention in the form of an improvement to an electrical machine
5 described in co-pending US Patent Application Number 10/273,238, incorporated herein by reference, consists of several aspects designed to limit magnetic flux leakage and improve flow of magnetic flux, each of which can be used singly or in combination to improve performance.

Figure 1 shows an exploded assembly view of an electrical machine employing all
10 parts of the improvement of the present invention. Figure 1 shows a magnet 2 in the shape of a cylindrical shell. In this embodiment magnetic north is radially outward and magnetic south is radially inward on the cylindrical shell shaped permanent magnet 2. Although the disclosure will use this magnetic orientation exclusively as to not cause confusion it is fully within the scope of the invention to have the magnetic orientation
15 reversed. It is also possible that the magnet 2 could be formed with the north and south poles oriented up and down, in which case the flux conductors would need to be suitably modified. A set of south flux conductors 4 are fixed such that they pass within the center of the magnet while making a good magnetic connection with the inner, south, surface of the magnet 2. A set of north flux conductors 6 are fixed around the outside of the magnet
20 2 and make a good magnetic connection with the outer, north, surface of the magnet 2. In this figure the south set of flux conductors 4 are shown split into two pieces and the magnet 2 and north flux conductors 6 are each a single piece. There are several ways to obtain the same resulting geometry with differently split components; for instance the

south flux conductors 4 could be made of a single piece, the magnet 2 could be simply a plurality of flat magnets placed circumferentially around the south flux conductors 4 with the north poles facing outward and south poles facing inward, thus approximating a cylindrical shell, and the north flux conductors 6 could be a two piece assembly split
5 along a diameter. Any suitable fabrication technique could be used to achieve the disclosed geometry and still be within the scope of this disclosure.

A groove 7 in the north flux conductor 6 contains a power coil 8. The power coil has leads 9 which conduct electrical power to and from the device of the present invention

10 A rotor cup 12 is mounted on a shaft 14 which spins in bearings 16. The rotor cup 12 contains a plurality of flux switches 18 which may be manufactured individually as shown or cast and/or machined out of a single piece. The flux switches 18 may be integral with the rotor cup 12 or they may be formed as separate components and bonded to the inside of rotor cup 12. In a 60 pole electrical machine there would be sixty flux
15 switches 18 spaced circumferentially 6 degrees apart.

The first aspect of the improvement of the present invention can be best illustrated by observing a cross section of the electrical machine as the rotor turns through one half cycle. Figure 2 and Figure 3 show the same cross section of the electrical machine one half cycle of rotation apart, so for a sixty pole machine Figure 3 would depict the
20 machine three degrees of rotation after Figure 2. It should be noted that the perspective stays stationary with respect to the rotor through Figures 2 and 3 such that the stator, including the flux conductors 4,6, is bisected at different points to illustrate the parts of

the flux conductors 4,6 that make contact with the flux switches 18 in each respective orientation.

Figure 2 shows that the north flux conductor 6 has an upper portion 20 with upper terminations 21 and a lower portion 22 with lower terminations 23. Between the upper and lower portions 20, 22 is the groove 7 which contains the power coil 8. A sixty pole electrical machine would have 60 upper terminations 21 spaced six degrees apart circumferentially and 60 lower terminations 23 spaced six degrees apart circumferentially. The upper and lower terminations 21, 23 are offset from each other such that in a sixty pole machine there would be 3 degrees of offset between the upper and lower terminations 21, 23. The use of the words 'upper' and 'lower' are only used to describe the relative position in the Figures as shown. Also, the pole spacing given for a 60 pole machine is for illustrative purpose only whereas, in practice, any number of poles may be used.

Figure 2 shows that the south flux conductor 4 has a top portion 24 with top terminations 25, and a bottom portion 26 with bottom terminations 27. Here the words top and bottom are used only to differentiate similar elements with reference to how they are positioned in the figures. Between the top and bottom portions 24, 26 of the south flux conductors 4 are contained the magnet 2, the north flux conductors 6, and the power coil 8. A gap 28 is left between the north and south flux conductors 4, 6 to minimize flux leakage between them. This gap 28 should be sufficiently large to virtually eliminate flux leakage. The gap 28 should be filled with a non magnetically conducting substance or left void. Within this gap 28, coils of wire connected to a power supply may be placed to act as an electromagnet to add to or subtract from the magnetic field of the permanent

magnet 2. An electromagnet may also be placed adjacent to, and concentric with, the permanent magnet 2 to augment or subtract from the magnetic field created by permanent magnet 2. The process of augmenting a permanent magnet's field with an electromagnet is fully described in co-pending US Patent Application Number 10/273,238. It should be noted that a first aspect of the improvement of the present invention is that this gap 28 contains much less surface area than the spaces between laminates as described in co-pending US Patent Application Number 10/273,238. Furthermore the gap 28 may be larger, i.e. have a greater distance between north and south magnetic material as compared to the electrical machine disclosed in co-pending US Patent Application Number 10/273,238. Thus magnetic leakage is decreased in two ways by this aspect of the improvement of the present invention, decreased surface area and greater distance between magnetic materials of opposite polarity.

Arrows in Figure 2 show the path of magnetic flux in the improved electrical machine in a first position. Starting from the magnet 2 flux flows radially outward in the upper portion 20 of the north flux conductor 6 and passes into the flux switch 18 through the upper terminations 21 of the north flux conductors 6. It should be noted that there is no lower termination 23 of the north flux conductors 6 in contact with a flux switch 18 at the time the electrical machine is in the position shown in Figure 2. Flux then flows down through the flux switch 18 and into the bottom portion 26 of the south flux conductor 4 through the bottom termination 27 of the south flux conductor 4. It should be noted that there is no top termination 25 of the south flux conductors 6 in contact with a flux switch 18 at the time the electrical machine is in the position shown in Figure 2. The flux flows radially inward through the bottom portion 26 of the south flux conductor

4 and then upward and returns to the magnet 2 through the magnet's south pole. The magnetic path shown in Figure 2 encircles the power coil 8 and causes magnetic flux to pass upward through the center of the coil 8 thus inducing current to flow in the power coil 8 into the page on the right hand side of Figure 2 and out of the page on the left hand side of Figure 2.

Arrows in Figure 3 show the path of magnetic flux in the improved electrical machine in a second position one half cycle after that shown in Figure 2. Starting from the magnet 2, flux flows radially outward in the lower portion 22 of the north flux conductor 6 and passes into the flux switch 18 through the lower termination 23 of the north flux conductors 6. It should be noted that there is no upper termination 21 of the north flux conductors 6 in contact with a flux switch 18 at the time the electrical machine is in the position shown in Figure 3. Flux then flows up through the flux switch 18 and into the top portion 24 of the south flux conductor 4 through the top termination 25 of the south flux conductor 4. It should be noted that there is no bottom termination 27 of the south flux conductors 4 in contact with a flux switch 18 at the time the electrical machine is in the position shown in Figure 3. The flux flows radially inward through the top portion 24 of the south flux conductor 4 and then downward and returns to the magnet 2 at the magnet's south pole. The magnetic path shown in Figure 3 encircles the power coil 8 and causes magnetic flux to pass downward through the center of the coil 8 thus inducing current to flow in the power coil 8 out of the page on the right hand side of Figure 3 and into the page on the left hand side of Figure 3. Thus the current flow in the power coil 8 is reversed between the orientations shown in Figure 2 and Figure 3, thereby completing one half cycle.

Figures 2 and 3 illustrate a different flux path sequence than that disclosed in co-pending US Patent Application Number 10/273,238 showing that there are different possible geometries within the scope of the invention using the concept of switched flux. The geometry disclosed in these embodiments provide for greater efficiency and greater number of poles in an electrical machine.

Figure 4 is a close up of the circle 4 in Figure 3 showing a side view of a portion of a flux switch 18 and a top termination 25 of a south flux conductor 4. A second aspect of the improvement of the present invention is illustrated in the serrated edges of the termination 25 and the flux switch 18. By necessity, there is some finite thickness of air gap 30 between the termination 25 and the flux switch 18. The thickness of the air gap 30 is exaggerated in Figure 4 for illustrative purposes. Though the air gap 30 is optimized to be as narrow as possible, this air gap 30 can be a major source of magnetic reluctance, thereby decreasing efficiency of the machine. The scale of the reluctance is a function of the thickness of the air gap 30 and is inversely proportional to the surface area of the air gap 30. The surface area can be increased by increasing the height or width of the termination 25 and switch 18 but this may not be desirable since it also increases the size of the electrical machine. The solution illustrated in Figure 4 is to create a serrated connection between the termination 25 and the flux switch 18 thus increasing the surface area of the air gap 30 and reducing reluctance. Figure 4 shows a serration with an angle of 45 degrees which increases the length of the region of contact and thus the surface area by 160%, and therefore decreasing the magnetic reluctance by 62%.

Figure 5 shows a top view of flux switches 18, several top terminations 25 of the south flux conductor 4 and several upper terminations 21 of the north flux conductor 6.

A third aspect of the improvement of the present invention is shown in the tapered contacting edge of the flux switches 18 and flux conductor terminations 25, 21.

The interface between the flux conductors 4, 6 and the flux switches 18 is at a predetermined diameter. By way of example only, that diameter could be 6 inches which gives a circumference at the interface of 18.85 inches. If the terminations of the flux conductors 4,6 and flux switches 18 have a non-tapered thickness of 1/8 inch (again, by way of example only) then it is necessary to have a gap of at least 1/8 inch between adjacent terminations of the same polarity at the interface diameter. This means that each termination and its respective gap occupy a total of 1/4 inch at the 3 inch radius. This allows a total of 18.85 inches divided by 0.25 inches, or 75 poles. In practice, the number of poles would be somewhat lower because the air gap between adjacent flux conductors must be slightly larger than the thickness of the flux switch to avoid simultaneous contact between the flux switch 18 and two adjacent terminations of the same polarity.

However, by forming the flux the terminations 25, 21 of the flux conductors 4,6 and flux switches 18 with tapered ends, the thickness of the terminations 25, 21 and flux switches 18 at the interface width is smaller and the gap can be made smaller. The terminations 23 and 27 are also tapered but are not shown in figure 5. For instance, if the terminations 25, 21 and flux switches 18 taper from 1/8 inch at the root of the serrations to 1/16 inch at the tip of the serrations (again, these dimensions are for illustration purposes only), then the thickness at the interface diameter would be approximately 3/32 inch. This means that the gap between adjacent terminations the same polarity only needs to be 3/32 inch for a total thickness of termination 25, 21 and respective gap of 3/16 inch. This allows a total number of poles of 18.85 inches divided

by 3/16 inches, or 100 poles. In practice, the number of poles would be somewhat lower because the air gap between adjacent flux conductors must be slightly larger than the thickness of the flux switch to avoid simultaneous contact between the flux switch 18 and two adjacent terminations of the same polarity. Therefore, by providing tapered terminations to the flux conductors 4, 6 and flux switches 18, it may be possible to increase the number of poles by up to 33% for a given diameter machine. Conversely, rather than providing a larger number of poles for a given rotor diameter, it may be possible to reduce the electrical machine's diameter for a given number of poles by using tapered terminations 25, 21 on the flux conductors 4, 6 and the flux switches 18.

It can be seen from the preceding that the improvements of the present invention decrease flux leakage and flux impedance of the electrical machine described in co-pending US Patent Application Number 10/273,238. It should be noted that while these improvements were only described in a single embodiment it is intended to illustrate the nature of the improvements and applies to all the embodiments described and implied by co-pending US Patent Application Number 10/273,238 including a three phase machine, a machine with an internal rotor, etc. It should also be noted that the electrical machine of the present invention can be operated as either a motor or an alternator, as is the case with the device disclosed in US Patent Application Number 10/273,238.

While an embodiment of the invention has been shown and described, it will be apparent to those skilled in the art that various modifications may be made without departing from the scope of the invention. Therefore, it is intended that the invention not necessarily be limited to the particular embodiment described and illustrated herein.